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Analysis and Section of Processes for the Disposition of Excess Fissile Material from Nuclear Weapon Dismantlement in the United States

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ANALYSIS AND SELECTION OF PROCESSES FOR THE DISPOSITION OF EXCESS FISSILE MATERIAL FROM NUCLEAR WEAPON DISMANTLEMENT IN THE UNITED STATES

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Abstract

The end of the cold war and the acceleration of nuclear disarmament efforts by the United States (U.S.) and Russia are generating large quantities of surplus fissile nuclear materials that are no longer needed for military purposes. The safe and secure disposition of this surplus material to prevent theft or reuse in weapons has become a high priority for the U.S. Department of Energy (USDoE). Many options exist for storage and disposition (use or disposal) of these surplus materials. The criteria, which have been developed from the basis for a preliminary “screening” of options, to eliminate from further consideration those options that do not meet minimal requirements. Factors, or attributes, contained in the screening and selection criteria include: 1) resistance to theft and diversion by unauthorized parties, 2) resistance to retrieval, extraction, and reuse by the host nation, 3) technical viability, 4) environmental, safety, and health impacts, 5) cost effectiveness, 6) timeliness, 7) fostering of progress and cooperation with Russia and others, 8) public and institutional acceptance, and 9) additional benefits. The evaluation of environmental impacts, in accordance with the U.S. National Environmental Policy Act (NEPA) process, is an integral part of the overall evaluation process. Because of the variety of physical and chemical forms of the nuclear material inventory, and because of the large number of possible disposition technologies and final forms, several hundred possible pathways to disposition have been defined and have undergone a systematic selection process. Also, because nuclear material disposition will have far ranging impacts, extensive public, in the form of public and stakeholder, input was integral to the selection process.

The remaining options are now being assessed based on overall system performance and will use the multi-attribute utility analysis methodology to assess relative merit. This methodology ensures that all key criteria are properly weighted in the ranking process. It also assures that the assessments under conflicting objectives are properly balanced and weighted. This methodology can be used to assess the desirability of a particular scenario or sequence of interdependent decisions and chance events.

Introduction

As announced in the Notice of Intent (NOI) to prepare a Programmatic Environmental Impact Statement (PEIS)[1], the U.S. Department of Energy is currently conducting an evaluation process for disposition of surplus weapons-usable fissile materials determined excess to national security needs.

The principal focus of this evaluation is on the disposition of approximately 50 MT of surplus U.S. weapons-usable plutonium[2] and a greater quantity of surplus highly enriched uranium. Minor actinides and surplus U-233 are also being reviewed. A recent National Academy of Sciences Report[3] provided a similar evaluation framework and information relating to plutonium disposition options.

The first phase of the evaluation is a screening process to consider potential options and to select reasonable alternatives for the PEIS. The second phase of the evaluation will be a more thorough assessment of the reasonable alternatives in the PEIS along with a detailed technical, economic, and non-proliferation analysis process, which will determine one or more preferred alternatives, and ultimately support a Record of Decision.

Surplus Fissile Material Disposition Options

The National Academy of Science (NAS) published a study that discusses both the desirability of the disposition of excess Special Nuclear Materials (SNM) and considers various possible options for the disposition of this excess material[4]. This study was used to provide an initial list of plutonium disposition options and as a resource of information for evaluating those options. Also, a number of technology options earlier considered by the DoE Office of Civilian Radioactive Waste Management[5] and various technology options under development at the DoE weapons laboratories were considered. In addition, options were brought to the attention of the DoE through the Public Scoping Workshops held from August through October 1994.

The disposition of surplus Pu is more than just managing the Pu recovered from nuclear weapons, it includes all of the surplus DoE owned Pu that is available and suitable for the manufacture of nuclear weapons. Processing and disposal requirements can vary substantially for the different material forms and composition. To facilitate the DoE screening process, a standardized format was prepared to describe and characterize possible options to describe the end-to-end process and final disposition locations, rather than just describing principal technologies.

The approach used in developing a list of potentially viable options consisted of three phases: 1) determination of the surplus fissile material inventories by material type or chemical and metallurgical form which must be dispositioned, 2) identification of final ultimate disposition forms and ultimate disposition locations, and 3) determination of necessary processing options which are required or may be desirable to process starting inventories into a given form and location.

Plutonium Disposition Options

Using the identification of likely source forms and ultimate disposal site options required steps for processing, interim storage, denaturing (if any), and final processing for ultimate disposition were identified. The ultimate disposition sites identified include storage facilities, underground cavities at the Nevada Test Site, U.S. or foreign geological mined high level waste repositories, deep boreholes, space, ocean, underground rock and magma formations, and salt caverns (such as the Waste Isolation Pilot Plant in New Mexico).

In general, sufficient processing was added, such that all chemical and physical forms can be dispositioned at all ultimate disposition sites. Any complete option description would then consist of a set of at least one pathway to final disposition for each of the chemical and physical forms. This would not preclude later combining options for disposition of the various chemical and physical forms to optimize the overall disposition strategy.

On the basis of on this analysis, the following storage, direct disposal, immobilization, and reactor options were identified:

<u>Storage Options</u>
(S-1) No Plutonium Disposition Action (Continued Storage)
(S-2) Radiation Barrier Alloy (Storage with Enhanced Passive Security)

<u>Direct Disposal Options</u>
(D-1) Direct Emplacement in HLW Repository
(D-2) Emplacement in Deep Boreholes after Immobilization
(D-3) Direct Emplacement in Deep Boreholes
(D-4) Discard to the Waste Isolation Pilot Plant
(D-5) Hydraulic Fracturing into Underground Shale Formations
(D-6) Injection of Slurry into Deep Underground Wells
(D-7) Injection into Continental Magma
(D-8) Melting in Crystalline Rock
(D-9) Disposal under Ice Caps
(D-10) Seabed Disposal (Placement on Ocean Floor)
(D-11) Sub-seabed Emplacement
(D-12) Controlled Dilution in Oceans
(D-13) Deep Space Launch

<u>Immobilization with Radio nuclides (with Ultimate Geologic Disposal)</u>
(I-1) Underground Nuclear Detonation
(I-2) Immobilization in Borosilicate Glass (using Modified DWPF)
(I-3) Immobilization in Borosilicate Glass (using New Facility)
(I-4) Immobilization in Ceramics
(I-5) Immobilization in Metals
(I-6) Glass Material Oxidation / Dissolution System (GMODS)

<u>Reactor Options (with Ultimate Disposal in High Level Waste Repository)</u>
(R-1) EURATOM Commercial MOX Fabrication / Reactor Burning
(R-2) Existing Light Water Reactors (LWRs)
(R-2A) Partially Completed LWRs
(R-3) Evolutionary or Advanced LWRs
(R-4) Naval Propulsion Reactors
(R-5) Modular Helium Reactors (MHRs)
(R-6) CANDU Heavy Water Reactors
(R-7) Advanced Liquid Metal Reactors (ALMRs) with Pyroprocessing (one cycle)
(R-8) Accelerator-Based Conversion / Molten Salt Target
(R-9) Accelerator-Based Conversion / Particle Bed Target

(R-10) Existing LWRs with Reprocessing
(R-11) Evolutionary or Advanced LWRs with Reprocessing
(R-12) Accelerator-Driven MHRs
(R-13) ALMRs with Recycle
(R-14) Particle Bed Reactors
(R-15) Molten Salt Reactors

Uranium Disposition Options

While many of the same options evaluated for plutonium could have been also analyzed for HEU disposition, a more limited number of options were considered because the options disqualified or eliminated for plutonium disposition were viewed as also being unreasonable for disposition of highly enriched uranium.

Two factors significantly impact the disposition of surplus highly enriched uranium and result in options that were not available for disposition of other weapons-usable materials:

- The highly enriched uranium can be rendered non-weapons-usable by isotopic dilution to low enriched uranium.
- There is a substantial domestic market for low enriched uranium, which provides opportunities for net revenues to the U.S. Treasury through sale of the highly enriched uranium or the blended product that meets specifications for the commercial nuclear fuel market.

A total of nine disposition options for highly enriched uranium were evaluated to determine those considered reasonable alternatives for further evaluation in the Programmatic Environmental Impact Statement (PEIS), and in a detailed technical, economic, and non-proliferation evaluation process. The options for major federal actions in the disposition of surplus highly enriched uranium considered in the screening evaluations include the following:

(H-1) No HEU Disposition Action
(H-2) Direct Sale of HEU
(H-3) Emplacement of HEU in Deep Boreholes
(H-4) Vitrification of HEU with High Level Waste
(H-5) Blend to LEU (19% Enrichment) and Store Indefinitely
(H-6) Blend to LEU (19% Enrichment) and Sell
(H-7) Blend to LEU (5% Enrichment) and Store Indefinitely
(H-8) Blend to LEU (5% Enrichment) and Sell
(H-9) Blend to LEU (<1% Enrichment) and Discard as Waste

CRITERIA FOR SCREENING DISPOSITION OPTIONS

Introduction

Screening criteria was developed to guide the selection of options that best achieve the fissile nuclear material disposition goals of the U.S. Government. A preliminary version of these screening criteria was provided to the public in a process to encourage feedback, comments, and critique. This input was considered in establishing the final set of criteria discussed below. The criteria was developed to reflect the following overall goals developed in the initial strategic planning within the Department of Energy Office of Fissile Material Disposition:

a) Consistent with National policy and nonproliferation strategy, develop a national program for management, control, and disposition of all U.S. surplus, weapon-usable fissile nuclear materials which will:
   - Minimize or eliminate the risk that these materials will be reused in weapons.
   - Assure that environmental, safety, and health risks do not exceed acceptable norms.
   - Provide an exemplary model for other nations nuclear material disposition programs.
   - Be cost effective consistent with meeting strategic objectives and these programmatic goals.
   - Achieve government and public consensus through stakeholder and public involvement in the program planning and decision process.
b) Foster cooperation with Russia and other countries and help reach consensus in their implementation of comparable programs with similar goals.
c) Assure that, at the earliest practical date, all U.S. surplus fissile nuclear materials are placed in safe, controlled, inspectable storage.
d) Optimize and execute technical plans for disposing of surplus highly enriched uranium, or blending it down to low enriched uranium.

e) For weapon-usable plutonium, provide credible options which can be utilized for safe, controlled and long term disposition of approximately 50 MT of these materials.
f) Integrate the minor quantities of other surplus fissile material isotopes or byproducts of uranium, plutonium and other fissile actinides into this program.

Utilizing these goals, the Department of Energy and the Lawrence Livermore, Oak Ridge, Sandia and Los Alamos National Laboratories jointly developed a set of draft screening criteria. These criteria were extensively reviewed, both internally within the Department of Energy, as well as with the Interagency Working Group (IWG). These reviews resulted in a number of refinements to the draft criteria. The refined set of criteria were then presented to the public and stakeholders through a set of questionnaires and public hearings. Input from questionnaire responses, comments received during meetings, and written input to the department, were incorporated into the final criteria.

Public and Stakeholder Involvement

Public input on a proposed set of screening criteria was solicited to assure that a comprehensive range of considerations was used to evaluate potential options for the long term storage and disposition of weapons-usable fissile materials.

Two questionnaires were developed (one for long term storage and the other for disposition) to determine the views of the interested public on the relative importance of the proposed screening criteria, additional criteria that should be used, and why any of the proposed criteria may be inappropriate or unnecessary. One thousand copies of each questionnaire were included in the materials provided to people attending the 12 Scoping Workshops held during August through October 1994. Approximately 150 of each questionnaire were completed and returned.

In addition to public input via these questionnaires, there was input on the proposed screening criteria captured in the transcripts of discussions at the Scoping Workshops.[6] There was also input regarding criteria contained in written comments submitted to the Department of Energy during the public comment period on the Notice of Intent to prepare the Programmatic Environmental Impact Statement.[7]

Criteria Descriptions

<u>Criterion 1 - Resistance to Theft or Diversion by Unauthorized Parties (Applies to both Disposition and Storage)</u>

This first criterion was used to address the risk of theft of weapon-usable nuclear material primarily during transportation, storage, and processing. The threat was presumed to be primarily theft by terrorists, sub-national groups or aspiring nuclear states, in addition to potential theft by disgruntled employees. In general, this threat can be reduced by minimizing the handling and processing of the material and applying effective Safeguards and Security (S&S) measures. Important characteristics included the inherent attractiveness of the weapons-usable material, the number of transportation steps and sites involved, and the number and characteristics of the processing steps that influence the effectiveness of standard S&S practices.

Factors considered when applying this criterion were:

a) <u>Low inherent attractiveness</u>: This factor favored disposition options that minimize the attractiveness of the physical, chemical, or isotopic makeup of the nuclear material during processing, transportation or storage. The risk of theft (or weapon use) is reduced if material is only available in small quantities, is in a physical and chemical form or matrix that makes recovery difficult.
b) <u>Minimization of transportation & sites</u>: The more complex the logistics, the more opportunities there are for theft. Disposal scenarios that involve very complex logistics with many transfers and storage locations were considered to be more vulnerable to theft.
c) <u>Safeguards and security assurance</u>: The effectiveness of the S&S protection depends on the form of the fissile material and the characteristics of the processes and facilities involved in disposition activities.

A potential disqualifier for an option under this criteria would be the inability to meet the "Stored Weapons Standard" during processing or storage.

<u>Criterion 2 - Resistance to Retrieval, Extraction and Reuse by the Host Nation</u>

The goal is to make it unlikely that the surplus weapons-usable materials will ever be reused in weapons. High resistance to retrieval would provide confidence to other nations that a relatively large resource expenditure (cost and time) would be required to reconstruct the stockpile from disposed material. Barriers to reuse resulted from the form of the material, physical location of the material, and institutional controls (such as IAEA Safeguards).

Modification of the weapons-usable material to make it as difficult to use for weapons production as plutonium contained in spent commercial reactor fuel would make the proliferation and re-armament threat associated with the surplus plutonium would be no greater than the threat resulting from plutonium in spent fuel, and the surplus plutonium would no longer require a unique level of domestic and international safeguards. From the perspective of this criterion alone, it would be even better to make the weapons-usable material as difficult to use as mining and enriching natural uranium (i.e., reaching a natural uranium standard). However, the greater degree of proliferation resistance provided by technologies that go beyond the spent fuel standard were not determined to be worth the substantial additional time and cost required, especially in light of the significant quantities of plutonium that are already contained in spent fuel.

For the specific issues addressed in the Programmatic Environmental Impact Statement, the "Host Nation" is the United States for most of the options considered. However, the motivation for taking these actions are driven by concerns in Russia as well. How our actions would foster progress and cooperation with Russia to provide effective storage and disposition of their materials is addressed in Criterion 7 discussed below.

Factors considered when applying this criterion were:

a) <u>Difficulty of retrieval, extraction and reuse</u>: This factor considered the difficulty (reflected by cost and time) of retrieval of surplus plutonium and its reuse in weapons.
b) <u>Assurance of detection of retrieval and extraction</u>: This factor primarily dealt with how difficult the material would be to retrieve and extract in a clandestine manner, which depends on the ultimate material location and form.

A potential disqualifier for an option under this criteria would be if the risk of retrieval, extraction or reuse after disposition is no better than long term storage.

<u>Criterion 3 - Technical Viability</u>

There should be a high degree of confidence that an alternative will be technically successful. It is therefore of interest to rely on technologies that have been proven for similar applications and have a high likelihood of success. New technologies (or new applications of old technologies) may also require an extended period for licensing or regulatory approval due to the immaturity of the process. This included the state, readiness and projected lifetime of facilities and infrastructure and the processing/storage/disposal capacity of the facilities.

a) <u>Technical maturity (applies to disposition options only)</u>: Near term actions require mature and proven processes. Technologies that are less mature would require a number of years to prove themselves and impose risks that they will not meet technical goals, be adequately mature for deployment, or be more costly than projected.
b) <u>Capacity/capabilities of facilities and infrastructure</u>: The capacity and capabilities of facilities that would be employed by an option was considered. This applies to both processing facilities that convert material into a form suitable for long term storage or disposition, as well as the capacity of above or below ground repositories and/or waste repositories.
c) <u>Regulatory/licensing</u>: Regulatory and licensing requirements were considered for almost all aspects of proposed disposition or storage options. New facilities, or the use of new technologies, may be more difficult to license or certify for operation. In some cases, this may be site dependent since state and local, as well as Federal regulations, will almost certainly apply. Since legislation, regulations, and permitting requirements are constantly evolving, long term projections or estimates were made. This introduced an element of project risk that was considered in weighing an option.

Potential disqualifiers for an option under this criteria would be: 1) no assurance of demonstrating technical feasibility in time for the option to be considered in the decision process, 2) key technology concept not likely to be demonstrated on a reasonable scale in a timely fashion, 3) capacities, or capabilities of facilities or infrastructure, are insufficient to accommodate the disposition mission within constraints not likely to be changed, or 4) Regulatory and licensing requirements are regarded as very uncertain and unlikely to be resolved in a timely fashion.

<u>Criterion 4 - Environment, Safety and Health</u>

The goal is to select options which would provide safe and healthy conditions for workers and the public and provide as little environmental impact as possible.

a) <u>Public and worker health and safety</u>: This factor considered the risk of public and worker exposure to radiation and hazardous materials during transportation, storage, processing and final disposition. Exposure to workers and the public under normal operating conditions and in the event of an accident were considered.
b) <u>Waste minimization</u>: This factor considered the potential impact of the waste created by the disposition option including transportation, storage, processing and final disposition. It assessed the long term, irreversible consequences of the disposition which are not captured by cost.

c) Known and manageable waste forms: This factor considered the ability to deal with the waste created by the disposition option. It would screen out options which create waste for which there is no known or likely practical treatment or disposal capability, because the technical viability or costs of dealing with these wastes cannot be readily estimated.
d) Environment and resource conservation: This factor considered the overall environmental impact of the storage or disposition option, including use of scarce resources, which is not captured by cost.

Potential disqualifiers for an option under this criteria would be: 1) unacceptably high probability of severe accident, 2) compliance with ES&H regulations is unlikely, or 3) wastes are created for which there is no known or practical disposal technology, capability or projected repository capacity.

Criterion 5 - Cost Effectiveness

A goal of the program is to minimize the incremental cost impact on the government and taxpayers. Timing, allocation, and variability of costs were assessed. The following cost related performance factors were considered to evaluate the extent to which a particular option is cost effective.

a) Life cycle cost: Life cycle cost is defined as the net present value of all incremental cash flows. Life cycle cost includes adjustments for revenues that may be produced by electric power production, but does not include the sunk costs of existing facilities or other costs that would be incurred whether or not any action is taken.
b) Investment and start up: Investment and start up cost refers to research and development, construction, retrofit, and program infrastructure costs that are incurred early in the program.
c) Potential for cost sharing: The potential for cost sharing refers to the willingness of other government agencies, or private industry, to partially fund the disposition effort. Some disposition options may provide benefits to these organizations, such as demonstration of a new technology or production of a useful product. These organizations may be willing to provide some funding.
d) Cost estimate certainty: Cost estimate certainty refers to the level of confidence regarding the forecast cost of an option and the actual cost that would be incurred if the option is selected. Cost estimates must be based upon assumptions and approximations and may be in error. Cost estimate certainty was lower for those technology options that are in the research or development stage and higher for mature technologies or existing facilities.

Potential disqualifiers for an option under this criteria would be that life cycle or start-up and investment costs, whichever are the more significant, are an order of magnitude greater than the average of those costs for other similarly desirable, but less expensive options or there is no rational basis for estimating the costs of the option and it is impractical to develop one.

Criterion 6 - Timeliness

A goal of the program is to act in a timely manner. This could reduce the risks of theft or diversion of weapons material and would send a positive signal to the international community regarding disarmament. The following schedule related factors were developed to evaluate the extent to which a particular option is timely.

a) Time to start disposition/Time to open: The time required to start disposition, or open a facility for long term storage, is one measure of timeliness. Options that show progress sooner were preferred.
b) Time to complete disposition/Time to complete transition: The time required to complete disposition is another measure of timeliness. Options that would complete disposition or storage transition sooner were preferred.
c) Schedule: Schedule certainty refers to the level of confidence regarding the forecast schedule of an option and the actual schedule that would be realized if the option was selected. Schedule estimates must be based upon assumptions and approximations, and may be in error. Schedule certainty was lower for those technology options that are in the research or development stage and higher for mature technologies and/or existing facilities.

Potential disqualifiers for an option under this criteria would be: 1) disposition could not begin within ~15 years, 2) overall disposition program would not be completed within ~30 years after initiation, or 3) no rational, substantive basis exists or can be developed for evaluating the schedule.

Criterion 7 - Fosters Progress and Cooperation with Russia and Other Countries

In view of the current political and economic instability in Russia, it is important that long term storage and disposition activities in the U.S. provide a model for or otherwise promote timely implementation of secure monitoring regimes and ultimate disposition of nuclear materials in Russia and other countries.

The factors listed below identify the features of storage or disposition options that were considered to lead to a more secure status of weapon-usable nuclear material in other countries.

a) Reciprocity and: The goal is to implement disposition and storage options that are jointly developed, or transferable, to Russia and other countries or will influence comparable actions that achieve similar results. In view of the lack of capital, the surplus of skilled labor, and the need for nuclear fuel in civil reactors in Russia, it is important to consider disposition and storage options that utilize these resources appropriately. For an option to be equivalent, it must generally be agreed that the risks of materials being reused in weapons, either by the nuclear-capable state or any other group, are comparable for the two approaches.
b) Compliance with treaties or agreements: This factor considered implications of various international treaties, or agreements, that may directly, or indirectly, be impacted by storage or disposition options. It screened out options that would violate international treaties.
c) Transparency: It is desirable that disposition activities in the U.S., Russia, and other declared nuclear states, be observable by IAEA and signatories to the Non Proliferation Treaty and provide assurances that weapons stockpiles of nuclear states are being reduced. Assessments were based on the availability of procedures and technologies for observing fissile material processing and material accounting systems. Consideration of the difficulty to reverse the disposition process in a clandestine fashion are captured in Criterion 2.
d) Timeliness: While timeliness of U.S. implementation of disposition options is captured in Criterion 6, implementation times might be much different for Russia and other countries.
e) Economic factors and defense conversion: Funding for plutonium disposition efforts is a major concern, particularly in Russia. Disposition options that are supported by other institutions, or private industry, were considered to be more desirable because they hold the promise of outside funding. Potential for funding from governments, institutions or private sources, or for international, or joint operations, were considered. The threat of migration of nuclear weapons expertise and hardware to proliferant nations, or sub national groups, could be reduced if personnel knowledgeable in nuclear weapons were utilized in disposition activities. Disposition options that employ large numbers of weapons scientists would be desirable. In addition, it would be desirable to select disposition options that provided cross training for personnel previously involved in weapons production so that they would acquire marketable skill outside of the weapons complex.

Potential disqualifiers for an option under this criteria would be violation of treaties or international agreements which are not likely to be changed or neither the process nor the final condition is amenable to transparent confirmation by international inspections.

Criterion 8 - Public and Institutional Acceptance

A goal of the program is to select alternatives that are acceptable to the public and cognizant government agencies. It is anticipated that each option will incur some amount of opposition from various governmental agencies, public interest groups, or individuals. An option that is generally acceptable is preferred.

a) Ability to create a sustainable consensus: This factor considered the ability to generate and maintain a broad constituency for a particular option. This is important since changes in governmental bodies will occur throughout the implementation time period.
b) Socioeconomic: Positive socioeconomic impacts include an increase in the tax base for local governments or employment base for citizens where facilities are being constructed or staffed. Negative socioeconomic impacts include disruption of a local community due to increased traffic, denial of land use for other purposes, and the boom-bust economic cycle associated with construction or site abandonment.
c) Policy/statute compatibility: One measure of the potential for gaining approval is the degree to which selection of an option is compatible with existing policies and statutes. The need for significant legislative or regulatory changes may imply an incompatibility with current public interests.

A potential disqualifier for an option under this criteria would be if there are violations of national policies, international treaties, or statutes which are not likely to be changed.

Criterion 9 - Additional Benefits

A number of the options proposed for disposition may have potential benefits to the Government, the commercial sector, and the public in general. These potential additional benefits were considered when evaluating options as a positive factor. However, a lack of additional benefits was not a negative factor.

a) Facilitates achievement of other government missions: Some options could benefit other government missions through the sharing of costs, and other burdens, with other Department of Energy, Department of Defense or other government agencies. In addition some reactor options have a dual use in that tritium or medical isotopes can be produced as a byproduct of fissile material burning.

b) Contributes to commercial initiatives: Options that develop capabilities, facilities, or trained personnel that can be shared with, or will benefit the U.S. commercial sector enhance the disposition program.

c) Potential technology spin-offs: Options that develop new technologies or intellectual property that can be shared with, or will benefit the U.S. commercial sector, provide additional benefits to the disposition program.

Most criteria have a “potential disqualified” that was used to identify potentially serious flaws or weaknesses of an option. For example, an option which would ostensibly violate a major treaty or international agreement implemented by U.S. law would be ruled out from further consideration under the “Public and Institutional Acceptance” criterion. Table 1 lists the potentially disqualifying factors for each storage and disposition criterion. Options which have one or several of these characteristics were disqualified in the screening process.

MULTI-ATTRIBUTE UTILITY THEORY AND DECISION TREES

Fissile nuclear material disposition activities will be directed toward achieving a number of disparate, often conflicting objectives (e.g., timely, cost effective, safe, positive influence on Russian disposition efforts, etc.). The decision criteria described here can be used to determine how well a given disposition alternative meets a goal. For example, one goal is to minimize the impact of disposition activities on public health (Goal 1b from the list of seven goals on page 5). The decision criterion “person-rem of radiation dose“ could be used to measure the extent to which a proposed disposition alternative meets this objective.

The decision criteria included in this document were intended to be used in a two stage procedure. In the first stage, the screening stage, threshold levels for attributes were used to eliminate unsuitable options. For example, if 100 man-rem were established as a threshold level, then disposition alternatives that involve population doses in excess of this threshold would be eliminated from further consideration.

In the second stage, the detailed evaluation stage, disposition options that pass the screening stage will be evaluated and compared in terms of their overall performance. The NEPA evaluation process, through a PEIS, will be an integral part of this stage as discussed further in Section III.E. Because it is unlikely that a single disposition option will be superior with respect to all goals, a means of establishing a weighting for each metric and for combining scales for different attribute and metrics is needed. The resulting weighting scheme will necessarily incorporate subjective value judgments on behalf of decision makers. Multi-attribute utility analysis is the recommended methodology for developing the weighting algorithm for combining them. The methodology was used to evaluate sites for a nuclear waste repository in a study that received a letter of commendation from the National Research Council.[8]

The multi-attribute utility function can be used to assess the desirability of a particular scenario, or sequence of interdependent decisions and chance events. A decision tree is a convenient structure for representing these scenarios. The decision tree represents all possible combinations of chance events and decisions, and algorithms can be used to find the optimal sequence of decisions. Using the decision tree structure and available computer packages, extensive sensitivity analyses can be performed and probability distributions on outcomes can be generated.

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